Customized gas turbine upgrade program boosts Cogen power output

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Through an ongoing series of customized adjustments to boost efficiency - ranging from inlet fogging and interstage injection to new inlet filters and turbine blade tips - the Watson Cogeneration Plant in Carson, Calif., has found several ways to gain an additional 45 MW out of existing GE Frame 7EA turbines.

"We started at 385 MW output, combined cycle, and are now at 410 to 420 MW without adding a single generator," says Watson Cogeneration principal engineer Steve Ingistov. "Instead, we achieved this by minimizing parasitic losses in gas turbines and by optimizing the processes to create greater efficiencies."

While this type of a power boost would help any power generator's bottom line, this is particularly important in an area such as California's tightly regulated South Coast Air Basin, where it is difficult to gain approval for any additional capacity.

Watson Cogen is headquartered in Carson, an industrial area about 15 miles south of downtown Los Angeles. A joint venture of BP Amoco and Mission Energy, it provides high-pressure steam to BP's Carson Refinery, as well as electricity to both the refinery and the grid. The 275,000 barrel per day refinery is California's largest, producing 20 percent of the state's gasoline and 30 percent of its diesel fuel as well as jet fuel and anode grade coke. As a byproduct, the facility also produces the fuel gas powering Watson Cogen's turbines.

Watson Cogen uses four natural gas-fired General Electric Model 7EA turbines rated at 83.5 MW each (ISO). Exhaust gases from these turbines feed a heat recovery steam generator, which generates both high and medium pressure steam. Half the high-pressure steam goes to the refinery, while the rest gets sent to two Dresser Rand steam turbines powering electric generators.

KEEPING UP THE PRESSURE

To optimize system performance, Watson changed every aspect of the system, from the air intake through the turbine expansion buckets and out to the steam recovery turbines. Since pressure drops across the inlet air structure affect gas turbine performance, Watson Cogen worked to reduce these losses. The silencer panels, for example, came with rectangular leading and trailing edges. These were reconfigured with rounded inlets and aerodynamically profiled tail sections. A larger filter element was installed and Venturi tubes for "Huff and Puff' self-cleaning intake air filters were eliminated. Taken together, these changes reduced the inlet air pressure drop by 1.7 inches of water. On this type of gas turbine a 1.7 inch reduction in inlet pressure drop increases baseload output by 0.6 percent and combined-cycle output by 0.5 percent, with a commensurate improvement in heat rate. This translates into significant annual fuel savings.

Photo 1. Brush and labyrinth seal assembly on Bearing No. 2.

Moving down the line, Ingistov addressed compressor eficiency. For gas turbines using a single shaft axial compressor, about half the turbine's power output satisfies compressor demands. The amount of work the compressor consumes depends largely on the ambient conditions such as air pressure, temperature and humidity. The turbine uses a constant volume of air, but the power generated depends upon the mass flow of the air. Warm moist air is less dense than cool dry air and so results in lower power output. In addition, warm air is much harder to compress than cool air, again leaving less available energy for turning the generator. Electrical demand is highest during warm summer afternoons when the air is also the least dense.

Cooling the air on warm days, therefore, results in denser inlet air and increased power output. Watson, therefore, first installed a 200 gpm evaporative cooler. It soon found, however, that at that flow rate, water droplets were being carried by the inlet air through the inlet air filter and onto the compressor blades. The impurities in the water, as well as the submicron particles released in the air by the evaporative cooler, would then foul the compressor blades causing a considerable increase in the power demand for compressing a constant volume of air.

As a result, the evaporative cooler was scaled back to 150 gpm, but this meant a reduction in cooling capacity. To achieve maximum air cooling, Watson Cogen installed an inlet air fogging system from Mee Industries to supplement the evaporative cooler. The system consists of a pump skid and a nozzle array connected by a latticework of stainless steel tubing (Figure 1). On the skid is a triplex pump to pressurize the water to 2,000 psi, a weather station and a programmable logic controller. Within the inlet air duct, downstream of the silencers and before the trash screen, is an array of 360, 0.006-inch diameter stainless steel impaction pin Mee Fog nozzles designed to atomize the water into droplets of less than 10 microns each for rapid evaporation. This array produces up to 16.2 gpm of fog, which represents 0.35 percent of mass flow used for intercooling.

Ingistov is convinced that installing the fogging system downsteam of the silencers is preferable. He cites Watson's first attempt at fogging, when the nozzles were installed upstream of the silencers. The fog washed the accumulated dirt off the silencers and carried it downstream, where it fouled the first stage compressor blades.

OVERFOGGING

The fog system at Watson is designed so that the fog mist does not evaporate before reaching the first compressor stage. With this method, called "overfogging," excess fog is injected into the air stream so that it will evaporate inside the compressor. As the air temperature rises during compression, the excess fog evaporates, bringing the air temperature down and thereby making it easier to compress the air. This process continues up to the eighth compression stage. In this case, the system is designed so that 10 percent of the water evaporates before reaching the compressor, with the remainder evaporating inside the compressor.

"With the fogging, we achieved an average incremental power gain per gas turbine unit of about 2.50 MW, or 10 MW total for the plant," says Ingistov, "while measurements of NOx at the top of the stack showed a decrease of 4 ppm."

While the above actions considerably improved power output, Ingistov also moved to reduce the parasitic losses with the turbine itself. Due to the pressure difference between the suction and pressure sides of the blades, the hot gases tend to flow over the tip of the blade to the back side of the aerofoil. According to Ingistov, each additional 0.020 inch radial gap results in a 1 MW loss. Watson, therefore, installed new first-stage blade tips designed and modified by Liburdi Engineering.

The second stage blades include a shroud as part of the blade casting and each shroud has two parallel rails to reduce the hot gas flow over the tips. The shroud block is furnished with bronzed honeycomb material. Watson had Liburdi install new cutter teeth on each of the stage two blade shrouds to cut grooves in the honeycomb to further retard the leakage of hot gases around the blade tips. When the turbine is operating under full load, centrifugal forces, gas dynamic forces and differential expansion between the rotor on the housing force the tip of the cutter teeth into the honeycomb.

FIGURE 1

Ingistov also decided to replace the OEM-supplied honeycomb with one manufactured by the English firm Neomet Ltd., which was selected for its ductility and resilience to hot corrosion attacks. Liburdi Engineering brazed the honeycomb to the stainless steel shroud block. The new teeth and the honeycomb resulted in a 0.30 MW output increase. Watson implemented similar changes to the third stage but, since the third stage runs much cooler than the second, it only produced half the gain achieved on the second stage.

KEEPING IT CLEAN

In addition to boosting power output, Ingistov also wanted to find ways to slow down the gradual power loss that occurs over time. Minute particles in the air, too small to be trapped by the inlet filters, enter the compressor and deposit on the compressor blades. This process is enhanced by oil mist from the bearings. Since these particles have almost no mass, the centrifugal forces are too small to overcome the particles' stiction and so they stay on the blades. Over time these particles build up to the point where the added drag on the blades cuts the power output from each turbine generator. While these particles can be washed off, that entails shutting down the generator.

Photo 2. Second-stage shroud blocks with brazed honeycomb.

So, in the spring of 2000, Watson started using compressor wash water inside the compressors in another way interstage injection. Rather than adding the compressor wash water to the inlet air, it is injected directly between the stator blades. Unlike fogging, the purpose is not to boost power, but to prevent its gradual loss by keeping the compressor clean. Watson Cogen designed and partially fabricated its own water injection nozzles and devised special tooling to drill through the compressor casing. It built a circular manifold for each of the three stages where the interstage injection nozzles were to be installed. Up to 2 gpm of water is injected at each of these stages at pressures not exceeding 500 psi. The process worked.

"Initial tests showed that the operating period between the offline compressor washes was \essentially doubled and the power losses associated with compressor fouling were less than half," says Ingistov. "The operating results proved the interstage injection concept of preserving the power rather than enhancing the GT power."

But even better than removing the dirt after the fact would be to keep it from getting there in the first place. To address this issue, Watson Cogen is in the process of installing a brand new non- metallic brush seal on bearing #1 just before the compressor intake. This seal serves to minimize the amount of dirty ambient air and oil mist entering the compressor from bearing #1. These seals have been installed on two compressors and they are producing the desired results.

"The space just upstream of the first compressor disk is normally under slight vacuum that may be as high as twenty inches of water," explains Ingistov. "This slight vacuum condition will encourage leakage of dirty and oily air into the compressed air path."

This then leads to a light coating of oil on the compressor blades, which makes it easier for dirt particles to stick. Ingistov estimates that this paste on the blades produces enough drag to result in a loss of 6 MW on each turbine.

The company decided to use plastic rather than metallic bristles since they ride gentler on the shaft surface. In addition, Watson incorporated drainage into the design of a new labyrinth housing so that oil would not pool in front of the brush seal. Further, the plant replaced the compressor discharge brush seals and the bearing #2 brush seals, resulting in another 1.5 MW power gain on each gas turbine. In addition, the company rebladed six stages on the two steam turbine generators, boosting them from 33 MW to 41 MW each, a total gain of 16 MW

CONTINUOUS IMPROVEMENT

But the story doesn't stop there. While some people would be satisfied with an extra 45 MW, Ingistov thinks he can still get more. "My dream is to build a scaled down compressor rotor model to further understand the complex mixing of the inlet air and interstage injection water stream systems," he says. "All the equations that are known go up to an air velocity of 500 feet per minute, but inside the compressor the velocity is 30,000 feet per minute. That's why I feel we are sailing uncharted waters."

Since one can't scale down the compressor and still get the correct aerodynamics, Ingistov is looking at building a full-size, but single stage, compressor to test in the wind tunnel at a local university or perhaps at Mee Industries' research facility in Monrovia, Calif

But even if he never builds that model, Ingistov still has gone a long way toward improving the efficiency and reliability of his generators. But he does warn, just as they say in the commercials, "your results may vary." The modifications made at Watson Cogen were designed to meet the needs of his particular installation. A plant with air cleaner than Los Angeles may not get the same results from interstage injection, while one in a drier or warmer area might get a bigger boost out of inlet fogging. He also advises that the blade tips on the first stage buckets shouldn't be extended if the turbine is used for peaking.

The main thing is not necessarily to adopt any particular piece of technology, but to make an intelligent assessment of one's own needs and then determine how best to meet these needs.

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